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(54) Title: BEAM OVERLOADING SOLUTION FOR OVERLAPPED FIXED BEAMS

(57) Abstract

The present invention relates to a method for allocating beams transmitted from, and received at, positions in Earth orbit for communicating with portable, mobile and fixed terminals and gateways by forming footprints using fixed beam antennas on board satellites flying in orbits below geosynchronous altitude. The footprints illuminate an Earth–fixed grid, including Earth–fixed cells. The spacing of the beams is reduced to create a cluster of beams which operates as a single entity wherein a ratio of beams is an integer multiple n of an amount of down–converters. Responsibility for communication with the target Earth–fixed cell is switched from a first of the cluster of beams to a second of the cluster of beams when the target Earth–fixed cell is within an overlap region shared by the first and the second of the cluster of beams.

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BEAM OVERLOADING SOLUTION FOR OVERLAPPED FIXED BEAMS

Background of the Invention

Field of the Invention

The present invention relates to a satellite communications system and more particularly to a system for satellite communications that manages the association of antenna beams and Earth fixed cells.

Background Information

Over the past few years, several satellite communications systems have been proposed to enhance existing terrestrial cellular telephone networks. The present cellular telephone networks utilize fixed transmitting and receiving stations located in adjacent cells. In the cellular networks, central transmitting and receiving antennas are stationary and subscribers may communicate with one another while moving from cell to cell.

Some communications systems employ satellites in geosynchronous orbits. These satellites are in orbits that are so distant from the Earth that any communications using them will have detectable latency, i.e. a detectable delay. The satellites remain fixed relative to a position on the Earth. If a low Earth orbit (LEO) network of satellites is utilized to provide a low latency cellular communication system, then the transmitting and receiving antennas aboard each satellite in the network are constantly in motion relative to the earth because the spacecraft in LEO orbits will move rapidly across the sky over any given place on the ground. Each LEO satellite is only visible for a few minutes from a user's point of view, and any communication from the network that lasts more than a few minutes must be handed off to another satellite. Since the position of the LEO satellite is not fixed with

respect to a location on the ground, some LEO networks require complicated schemes for steering radio beams to users on the ground.

The fast moving LEO satellite spacecraft sweep radio beams across vast regions of the Earth's surface at the same rate of speed. If these beams were visible to the eye, they would paint bright circular and elliptical patches of light on the ground beneath the satellite which emitted them. In a system that employs satellite-fixed cells, the "footprint" of the radio beams propagated by the spacecraft defines a zone on the ground called a "cell" which is illuminated by the spacecraft. The satellite-fixed cell moves constantly as the spacecraft orbits around the globe.

An "Earth-fixed cell" is a stationary region mapped to an "Earth-fixed grid" and has permanent fixed boundaries. Although the rapidly moving LEO satellites shine their radio beams over the ground in rapidly moving footprints, the locations of the footprints at any given time do not determine the location of the unchanging Earth-fixed cells. The great advantage provided by using cells having boundaries that are fixed with respect to an Earth-fixed grid is realized when a subscriber being served by one satellite must switch to another beam in the same satellite or to a second satellite because the first is moving out of range below the local horizon. With Earth-fixed cells it is also possible to plan resource allocation. For example, LEO satellites passing over a high-use Earth-fixed cell know they must not accept additional demands until reaching the high-use cell.

The Earth-fixed cell method uses software that provides position and attitude information to each satellite in a constellation. Position data from the software enables each satellite to map the surface into the Earth-fixed group. Each satellite is capable of transmitting and receiving beams conveying packets of information to the Earth-fixed grid. The beams are continually adjusted to compensate for the effects of satellite motion, attitude changes and rotation of the Earth.

By using the Earth-fixed cell method, the Earth is divided into hexagonal, square, or any other shaped tiles and the satellite beams register on these cells. As discussed above, LEO satellites are in non-geostationary orbits (NGSO) and therefore move with respect to the Earth. As such, the antenna beams are required to track the position of the Earth-fixed cells, where each of the beams is assigned to cover an individual Earth-fixed cell. The satellite's ability to steer an individual beam is limited to a particular movement range about a nominal beam position.

In one method, as shown in Fig. 1, the satellite beams are electronically steered to track the relative movement of the Earth-fixed cells until they reach the edge of their movement range, then they are ratcheted back to cover a new cell. This form of tracking is referred to as "ratcheting a beam." The ratcheting beam concept, for example, a ratcheting beam Rotman lens ratcheting beam antenna, shown in Fig. 1, uses scanning beam antennas 102 to point at Earth-fixed cell centers with beams having a scan range that is less than a full footprint. The antennas 102 use a primary beam former 104 to create fixed component beams that are combined in a secondary beam former 106 to form and scan beams. The secondary beam former 106 is controlled by a beam forming network (BFN) 110. The BFN control 110 directs beams by combining various pencil beams using a complicated processing system including 3000 16-way splitters, 48,000 variable attenuators, 48,000 phase shifters, and 360 133-way combiners. The ratcheting beam assembly 100 also includes a typical down converter assembly 108. Unfortunately, because of the requirements of the secondary beam former 106, ratcheting a beam uplink antenna is expensive, it consumes large amounts of power, is heavy, and requires significant processing capability to determine when to move and where to point each beam. The greatest concern with ratcheting beam antennas is the highly complex packaging scheme required to form and scan beams.

Another form of satellite communication uses a phased array antenna that scans over an entire footprint. Unfortunately, a phased array antenna system that scans over the entire footprint is impractical because it requires the creation of hundreds of individually steered beams. For example, if a typical phased array antenna that produces four beams per aperture is used within a satellite that requires 360 beams to cover a footprint, then the satellite would require 90 antennas to service the footprint. This arrangement would require the size of the satellite and the cost of the antennas to be unreasonably large.

Yet another form of satellite communication system uses satellite-fixed non-overlapped beams 120, as shown in Fig. 2. However, this approach is generally not compatible with Earth-fixed cells since entire cells cannot be handed over from beam to beam. Also, the satellite-fixed beams do not necessarily register properly on Earth-fixed cells. For example, a cell 121 may be covered with three different beams, i.e., multiple beams 123 as show in Fig. 2. However, if this is the case, the demodulator resources 122 must be triple allocated because of the uncertainty of what users are in what beams 123. In other words, if three beams 123a–123c are all covering the one Earth-fixed cell 121, then each of the beams 123a–123c must have an allocation of the demodulators 122 capable of handling the entire Earth-fixed cell 121. Since demodulators are costly and a limited resource, such triple allocation is very undesirable.

Accordingly, there is a need for a simple, inexpensive means of managing satellite communications with Earth-fixed cells that does not require expensive and heavy hardware. There is also a need in the art for an inexpensive, reliable, continuous communication system including a call management system, that allows both users and satellites to always know what channels to operate on and the precise time to switch channels.

Summary of the Invention

The present invention relates to a method for allocating beams transmitted from, and received at, positions in Earth orbit for communicating with portable, mobile and fixed terminals and gateways by forming footprints using fixed beam antennas on board satellites flying in orbits below geosynchronous altitude. The footprints illuminate an Earth-fixed grid, including Earth-fixed cells. The spacing of the beams is reduced to create a cluster of beams which operates as a single entity wherein a ratio of beams is an integer multiple n of an amount of down-converters. Responsibility for communication with the target Earth-fixed cell is switched from a first of the cluster of beams to a second of the cluster of beams when the target Earth-fixed cell is within an overlap region shared by the first and second of the cluster of beams.

Brief Description of the Drawings

Figure 1 shows a prior art example of a Rotman lens ratcheting beam antenna;

Figure 2 shows a prior art concept of non-overlap fixed beams;

Figure 3 shows a first embodiment of the present invention utilizing a cell handover concept using overlapped satellite fixed beams;

Figure 4 shows the cell handover geometry for the overlapped satellite fixed beams of the present invention;

Figure 5 shows the cell handoff of a first beam to a second beam as performed in the present invention;

Figure 6 shows a satellite foot print comprising a plurality of overlapped fixed beams of the present invention;

Figure 7 shows a formation of a four beam cluster;

Figure 8 shows a cell handover between beam clusters;

Figure 9 shows a multiple beam array antenna; and

Figure 10 shows a graphical representation of the relationship between beam diameter, cell diameter, and beam spacing.

Detailed Description of the Invention

The present invention, as shown in Figs. 3 and 5, is a communication system 18 and a method for using overlapped satellite fixed beams 20 for satellite communication. The system 18 manages ground-based users by associating them with Earth-fixed cells 22, and handing over management of the Earth-fixed cells 22 in overlap regions 24 of the satellite fixed beams 20. The Earth-fixed cells 22 are sized in relation to the beams 20 and their overlap regions 24 such that the Earth-fixed cells 22 will always be entirely covered by a single one of the fixed beams 20. The present invention enables the Earth-fixed cells 22 to be handed off from one of the beams 20 to another of the beams 20 when the cell 22 is in a respectively shared one of the overlap regions 24 between the two subject beams 20.

Managing the Earth-fixed cells 22 is much simpler and more efficient than the alternative of managing individual users and, since resources can be shared within the Earth-fixed cells 22, there is a statistical multiplexing advantage. The present invention eliminates the need to steer and control antenna beams by using fixed beam antennas which are very simple to use and design, and no complex processing or heavy electronic equipment is required for beam steering.

The present invention preferably uses a greater number of smaller beams 20 that are grouped and managed as beam clusters 46, as shown in Fig. 7. A reduction of the diameter D of the beam 20 is achieved while maintaining a coverage area by replacing each large beam with the cluster 46 of smaller beams 20 connected by a switching mechanism 48. The Earth-fixed cells 22 are serviced by only one of the smaller beams 20 from the cluster 46 at any given time. This reduction in beam diameter D results in increased beam gain and a smaller reuse area. Increased gain/directivity offers an increased link margin. A smaller reuse area increases the

capacity density that can be served by the satellite. The beams 20 are considered overloaded because a number of smaller overlapped fixed beams 20 are combined with the single-pole-N-throw switch 48 to operate as a single entity. The present invention improves the service quality of the satellite communications system by reducing the diameter D of the beam 20 required to provide overlap for a given size of the Earth-fixed cell 22.

As shown in Figures 3 and 5, the present invention utilizes a fixed multi-beam antenna 40, which radiates the plurality of beams 20 to communicate with the Earth-fixed cells 22. The Earth-fixed cells 22 are handed over from one of the beams 20a to another of the beams 20b when they are contained within a mutual one of the overlap regions 24 between the beams 20. The transfer from one of the beams 20 to another of the beams 20 in a shared one of the overlap regions 24 allows the servicing of an Earth-fixed cell 22 by only a single one of the beams 20, instead of requiring the service by a plurality of the beams 20. The beam overlap regions 24 must be correctly sized so an Earth-fixed cell 22 is always contained within a single one of the beams 20. The size of the overlap regions 24 is controlled by either reducing the spacing (s) between beams 20 or by increasing the diameter (D) of each of the beams 20 within a beam lattice.

As shown in Fig. 4, the satellite fixed beams 20 pass over the Earth-fixed cells 22, and the cells 22 are handed over between the beams 20 when they register in the overlap regions 24. The required handover geometry, i.e. the size of the Earth-fixed cell 22 in relation to the overlap regions 24 of the beams 20 required to perform this process is calculated with beam geometry equations as follows:

$$\cos 30 = s/2 \,/\, (r_b - r_c); \text{ and}$$

$$r_c = r_b - .577s,$$

where r_c is the spacing of the Earth-fixed cells 22, r_b is the radius of the beams 20, and s is the spacing of the beams 20, as shown in Fig. 4. The necessary size of the

beam overlap regions 24 are determined by a triple overlap condition when the beams 20 are on a triangular lattice.

As shown in Fig. 5, cell hand off from the beam 20a to the beam 20b of the plurality of beams 20 occurs when the Earth-fixed cell 22 is in a mutually shared one of the beam overlap regions 24. The communication system 18 has demodulators 38 serving the cell 22 that are switched from the beam 20a to beam 20b. Reliability during handoff is increased since the demodulators 38 stay with the same Earth-fixed cell 22. Figure 5 shows that the communication system 18 includes eight demodulator channels allocated to the cell 22 being handed off. The multi-beam antenna (MBA) 40 forms overlap beams that are part of a larger lattice, as shown in Fig. 6 that cover up the satellite footprint. Since the satellites serving the Earth-fixed cells 22 are in a constant orbit, and the Earth-fixed cells 22 remain at a constant point on the Earth, handoff between beams or satellites can be executed based on a simple timing mechanism, as is well known in the art.

A requirement for broad-band communication systems is that the user terminals be inexpensive. A critical performance parameter for user terminals is Equivalent Isotropic Radiated Power (EIRP). Unfortunately, the higher the EIRP, the more expensive the user terminal. To be able to use an inexpensive user terminal that has a low user terminal EIRP, a satellite antenna must have a high antenna gain (G) over noise temperature (T) value, i.e., a high G/T, to close an up-link between the user terminal and the satellite. High satellite antenna gain (G) requires the use of narrow beams with small beam coverage areas on the Earth. Therefore, the satellite coverage area, i.e., footprint, usually consists of tens or hundreds of coverage beams arranged in the triangular lattice, shown in Fig. 6. Sufficient overlap must also exist between the satellite footprints such that the Earth-fixed cells 22 may be handed from satellite to satellite. The number of Earth-fixed cells 22 that may be serviced by a footprint of beams 20 will be determined by the above-described geometry equations.

In the overlap fixed beams configuration shown in Fig. 3, the diameter D of the beams 20 must relate to the diameter d of the Earth-fixed cells 22, such that a cell 22 can fit into the overlap regions 24 of the three beams spaced on the triangular lattice. The driving equation for the overlapped fixed beam configuration is:

$$r_c = r_b + \frac{1}{2\cos(\pi/6)}(s).$$

It is desirable to minimize beam radius in order to enhance the G/T. Similarly, it is desirable to maximize the cell radius r_c to reduce management complexity and improve statistical multiplexing capability. Therefore, it is desirable to minimize the beam spacing (s), which correlates to increasing the number of beams in the MBA 40. The number of beams in a footprint is related to the spacing of the beam 20 by the following equation:

$$\#\_of\_beams = \frac{1}{\cos(\pi/6)} \frac{footprint\_area}{s^2}.$$

Since the number of beams is inversely proportional to the square of the beam spacing (s), the spacing (s) of the beams 20 has serious implications on the number of beams 20 that must be formed in the MBA 40.

The beam geometry equations, discussed above, were used to create the following table:

# beams	Beam dia. (km)	Cell dia. (km)	# cells in FP	Beam spacing (km)	Delta G/T (dB)	Description
360	118	118	360	102	0	Baseline ratcheting beam
360	162.6	44.6	2520	102	-2.78	Uplink cell size = downlink cell size, fixed beam count
360	236	118	360	102	-6	# beams, #cells, cell size unchanged
720	118	34.8	4140	72.1	0	Double # of beams, beam diameter fixed
720	201.2	118	360	72.1	-4.6	Double # of beams, fix # of cells
720	168.2	83	720	72.1	-3	Double # of beams, fix # of cells
1440	168.9	118	360	51	-3.52	Quadruple # of beams, fix # of cells
1440	142	83	720	51	-1.6	Quadruple # of beams, double # of cells
2880	159.6	118	360	36.1	-2.63	8x number of beams, fix # of cells
2880	124.6	83	720	36.1	-0.5	8x number of beams, double # of cells

Each line of the above table represents a potential overlapped six-beam design. For comparison purposes, the top row defines a prior art ratcheting beam base-line design. For ratcheting beams, the beam diameter is equal to the cell diameter and there is no beam overlap.

In a first embodiment of the present invention, as described on the second line of the above table, a design has the number of beams set to 360, which is the same as

the ratcheting beam baseline. The overlap regions 24 are created by increasing the diameter D of the beams 20 from 118 km to 126.6 km in order to produce enough overlap to hand over a 44.6 km cell. The G/T is reduced by 2.78 db. as a result of increased beam diameter D.

Unfortunately, there is a performance penalty for overlapping the antenna beams of the present invention. For example, if the overlap regions 24 are created by enlarging the beam diameter D, then there is an antenna gain (G/T) penalty and an increasing frequency reuse distance. The G/T loss caused by an increased diameter D of the beams 20 generally results in a degraded link margin. To reduce this effect, the size of the Earth-fixed cells 22 can be reduced. The smaller the Earth-fixed cell 22, the smaller the required overlap regions 24, and the lower the G/T penalty. However, small cells have a potential statistical multiplexing penalty. Thus, in a preferred version of this embodiment, the present invention has small overlap regions 24 and diameters (d) of the Earth-fixed cells 22 that are a fraction of the diameter D of the beams 20.

In a second embodiment of the present invention, as shown in line 4 of the above table, the design of the present invention has no G/T loss relative to the ratcheting beam baseline. This is because the diameter D of the beam 20 was held constant at 118 km. Sufficient overlap to "hand off" the 34.8 km cells was created by doubling the number of beams 20 to create a total of 720 of the beams 20.

In a preferred third embodiment of the present invention, as described on the last line of the above table, the design has four times as many of the beams 20 as there are the Earth-fixed cells 22. Here, only one quarter of the beams 20 will be active at any time. A switch 48, shown in Fig. 7, is required to select the active beams. The switch is implemented at RF or, in the alternative, IF frequencies.

As the spacing (s) of the beam 20 decreases, the amount of overlap increases, as shown in Fig. 7. Eventually, as the antenna beam coverage per unit area increases

with increased overlap, processing of the data in the multiple beams becomes very inefficient. However, if the ratio of beams 20 to down-converters in the cluster 46 is designed as an integer multiple n, then each down-converter can be serviced by 1:n switch beams. The overlap of the beams 20 within the cluster must be sufficient such that a cell 22 can be completely serviced by one of the beams 20 in the cluster 46 for any registration of the cell 22 within the coverage area of the cluster 46. The switch 48 determines which of the beams 20 in the cluster 46 is actively covering the Earth-fixed cell 22.

The clusters 46 are preferably overlapped with other clusters 46 in a manner such that as the Earth-fixed cell 22 exits a first cluster 46a, it is automatically entering another second cluster 46b, as shown in Fig. 8. In this configuration, selection of beam to down converter mapping is similar to beam ratcheting. Also, if the diameter D of the beams 20 is less than twice of the diameter d of the cell 22, then only one beam 20 can serve any of the Earth-fixed cells 22 at any time. This feature simplifies the beam-to-cell mapping by preventing contention between two or more of the Earth-fixed cells 22 for service by the same antenna beam 20.

The MBA 40 is preferably the Rotman Lens Multiple Beam Array Antenna, because it has a low incremental cost for additional beams 20. Decreasing the spacing (s) of the beams 20 is particularly promising with this particular type of antenna. The Rotman Lens Multiple Beam Array Antenna 40 is shown in Fig. 9. The Rotman Lens implementation of the multi-beam array antenna 40 generates multiple fixed beams using the arrays 42 of one-dimensional dielectric lenses. The receive elements and the LNA's are located before the beam-forming network 44. The number of beams 20 generated by the array 42 is primarily driven by the number of beam ports in the array 42. Since the number of beams 20 is not driven by the number of the receive elements or the LNA's, the incremental cost to add beam ports to the Rotman Lens multi-beam array antenna 40 is relatively low.

Figure 10 shows the relationship between beam radius r_b, cell radius r_c, and number of beams, and is described by the following equation:

$$r_b = r_c + \frac{1}{2}\cos(\pi/6)^{-3/2}\sqrt{\frac{footprint\_area}{\#\_of\_beams}}$$

In figure 10, for every curve, the number of beams is varied from 360 to 4,000 and the beam diameter D is represented by the relative G/T value with reference to the G/T of a 118 km diameter beam. A G/T offset of zero decibels corresponds to 118 km beams and –6 db corresponds to 236 km beams. As seen from the curves, the beam overloading offers notable improvement in cell diameter d, beam diameter D, or both.

The third embodiment describing the overlapped six beams management approach is an improvement over the first and second embodiments of the overlapped fixed beams when it is implemented with an antenna that only requires small incremental costs to add additional beam ports, such as the Rotman Lens Multiple Beam Array Antenna, described above. With respect to a baseline configuration of 360 beams and 360 down-converters, increasing the number of beams by a factor of 8 improves the uploading antenna G/T by over 3 decibels. The improvement in G/T reduces the required maximum EIRP for user terminals or can be used to enhance the capacity density of the uplink communication service. Either utilization of the improved G/T offers significant improvement over the previously discussed overlapped fixed beam supplementations which do not use beam overloading. Only minimal additional costs are required to implement this embodiment. For example, additional hardware implementation such as 360 single-pole-8-throw switches and increased interconnects and dielectric beam-formers would be required.

In conclusion, Earth fixed-cell operation is the simplest and most robust approach to an LEO satellite communication system; however, it can be extremely complex, risky, and costly when a ratcheting beam antenna is used to enable the fixed-cell operation. The present invention solves the antenna problem by using a very

simple fixed-beam antenna that is inexpensive and has a long heritage in space. The performance or hardware cost associated with creating overlap between beams for cell handoff, i.e. G/T loss, can be reduced when the beams are overlapped by reducing the beam spacing and switching them in clusters. The associate hardware for the present invention is simpler and less expensive than the prior art ratcheting beam approach. Even if the number of beams is doubled, the associate hardware is still simpler and less expensive than the prior art ratcheting beam approach. Further, the present invention is fully compatible with existing Earth-fixed cell management concepts and users do not have to switch frequency when they transition from beam to beam. Finally, the present invention is simple to manage and is highly robust.

Except as otherwise disclosed herein, the components shown in outline or block form are individually well known and their internal construction and their operation is not critical either to the makings or the using of this invention or to a description of the best mode of the invention.

While a detailed description of the above has been expressed in terms of specific examples, those skilled in the arts will appreciate that many other configurations could be used to accomplish the purpose of t he disclosed invention. Accordingly, it will be appreciated that various equivalent modifications of the above-described embodiments may be made without departing from the spirit and scope of the invention.

CLAIMS

1. A method for allocating a plurality of beams transmitted from and received at positions in Earth orbit for communicating with a plurality of portable, mobile and fixed terminals and gateways, comprising the steps of:

forming a plurality of footprints using a plurality of fixed beam antennas being carried on board a plurality of satellites flying in orbits below geosynchronous altitude, said plurality of footprints illuminating an Earth-fixed grid, including a plurality of Earth-fixed cells;

reducing spacing of said beams to create a cluster of said beams, wherein a ratio of said beams in said cluster is an integer multiple n of an amount of down-converters, said cluster operating as a single entity;

switching responsibility for communication with a target Earth-fixed cell from a first one of said cluster of beams to a second one of said cluster of beams when said target Earth-fixed cell is within an overlap region shared by said first one and said second one of said cluster of beams.

2. A method for allocating a plurality of beams transmitted from and received at positions in Earth orbit for communicating with a plurality of portable, mobile and fixed terminals and gateways, comprising the steps of:

forming a plurality of footprints using a plurality of fixed beam antennas being carried on board a plurality of satellites flying in orbits below geosynchronous altitude, said plurality of footprints illuminating an Earth-fixed grid, including a plurality of Earth-fixed cells;

overlapping said plurality of beams by either reducing spacing of said beams or increasing a diameter of said beams, to create an overlap region between said plurality of beams;

switching responsibility for communication with a target Earth-fixed cell from one of said plurality of beams to another one of said plurality of beams when said target Earth-fixed cell is within the overlap region.

3. The method according to claim 2 wherein said plurality of beams form an overlapped triangular lattice.

4. The method according to claim 3 wherein said Earth-fixed cells have a spacing (s), each of said beams has a radius (r_b), and each of said Earth-fixed cells has a radius (r_c), said plurality of beams arranged in relation to said Earth-fixed cells such that:

$\cos 30 = S/2 \div (r_b - r_c)$ and $r_c = r_b - .577s$.

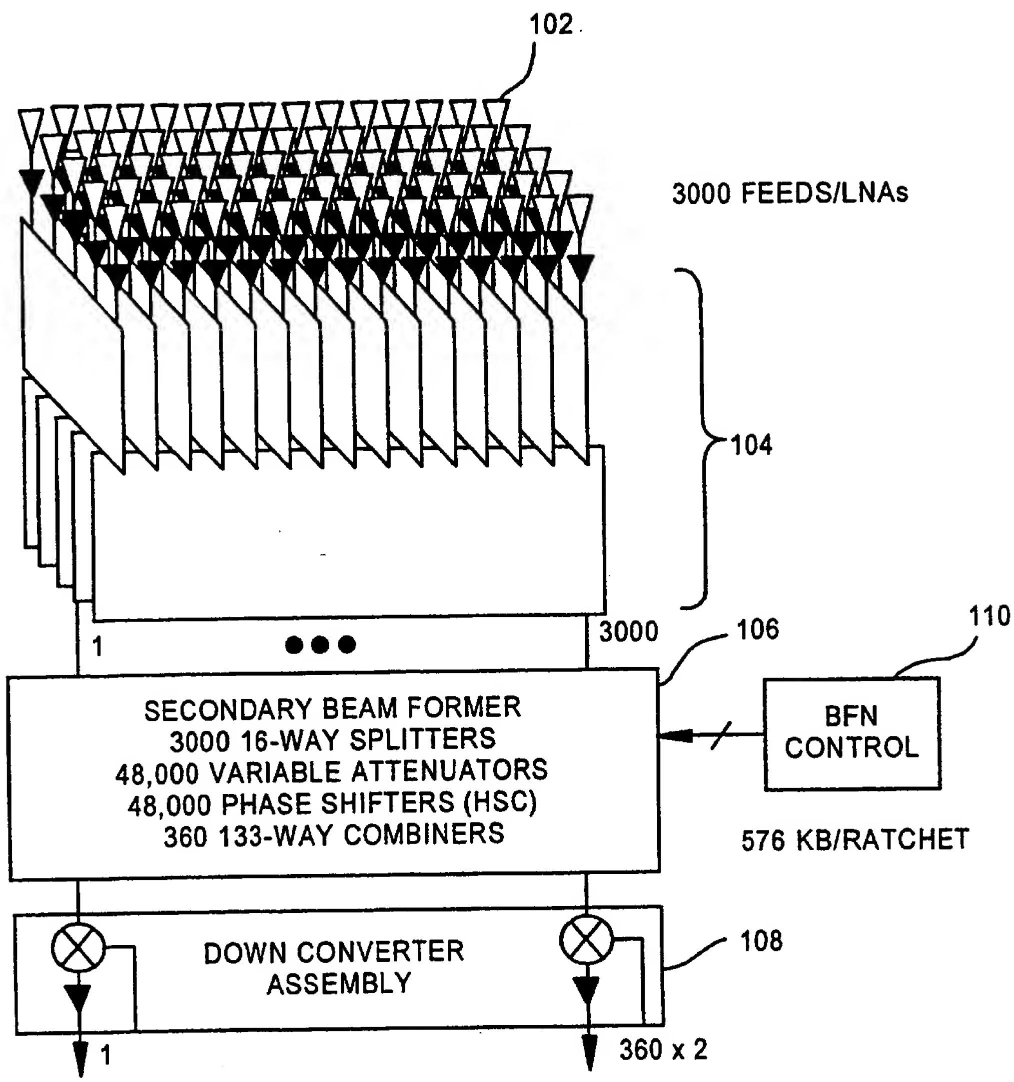

FIG.1
PRIOR ART

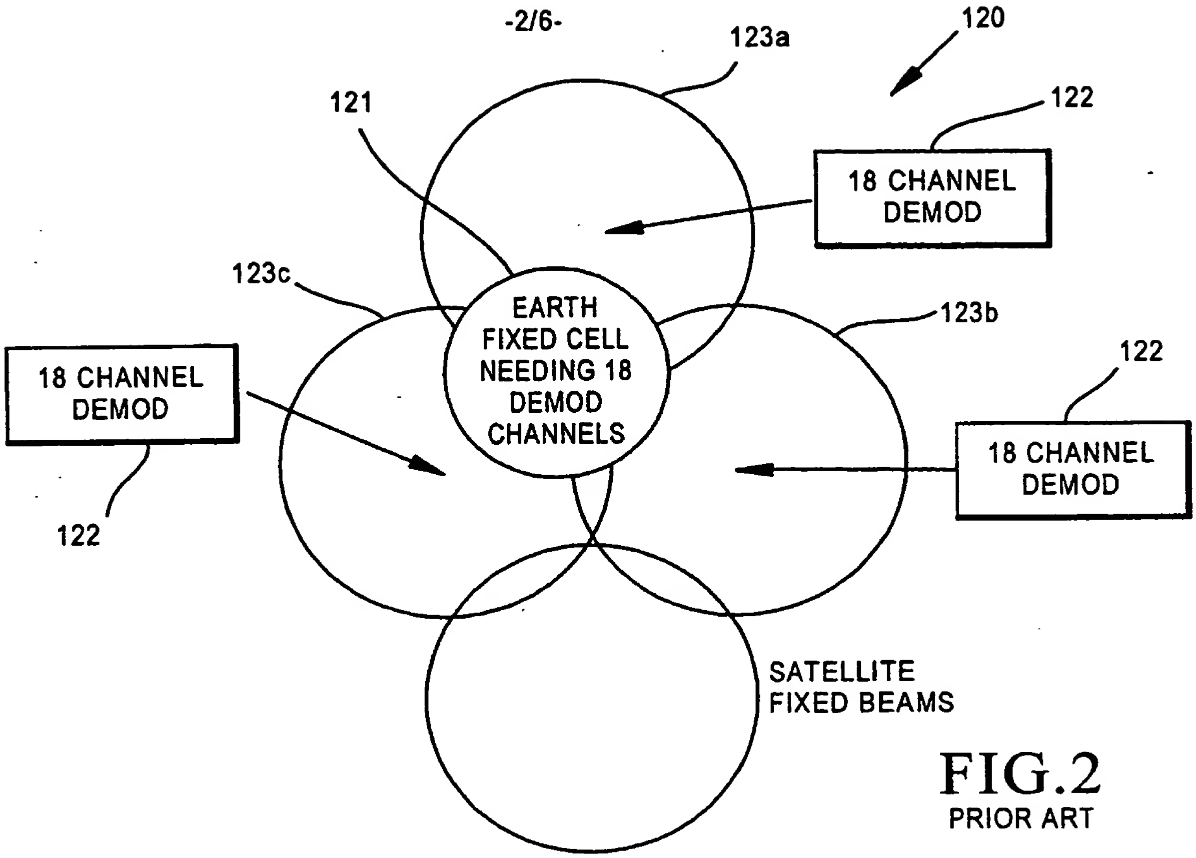

FIG.2
PRIOR ART

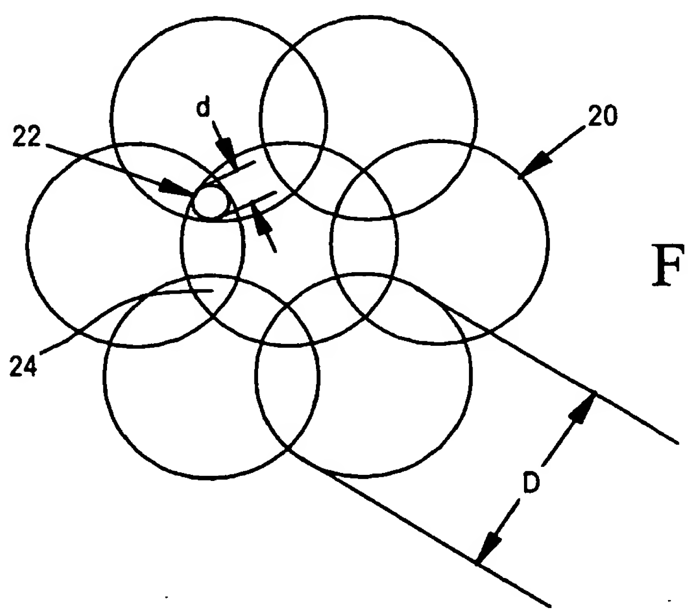

FIG.3

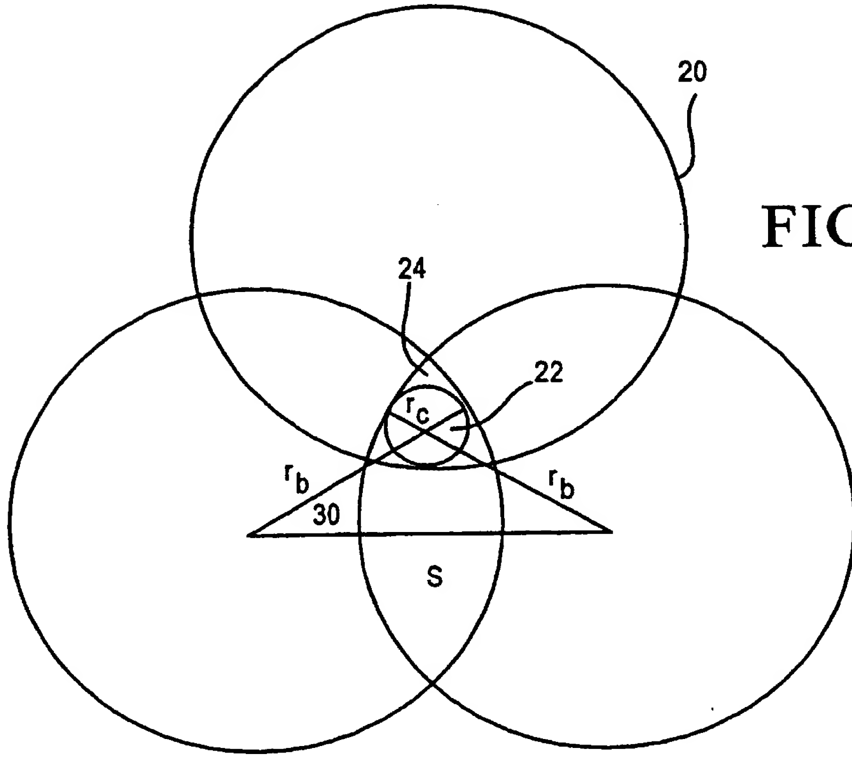
20
24
22
r_c
r_b
r_b
30
S

FIG.4

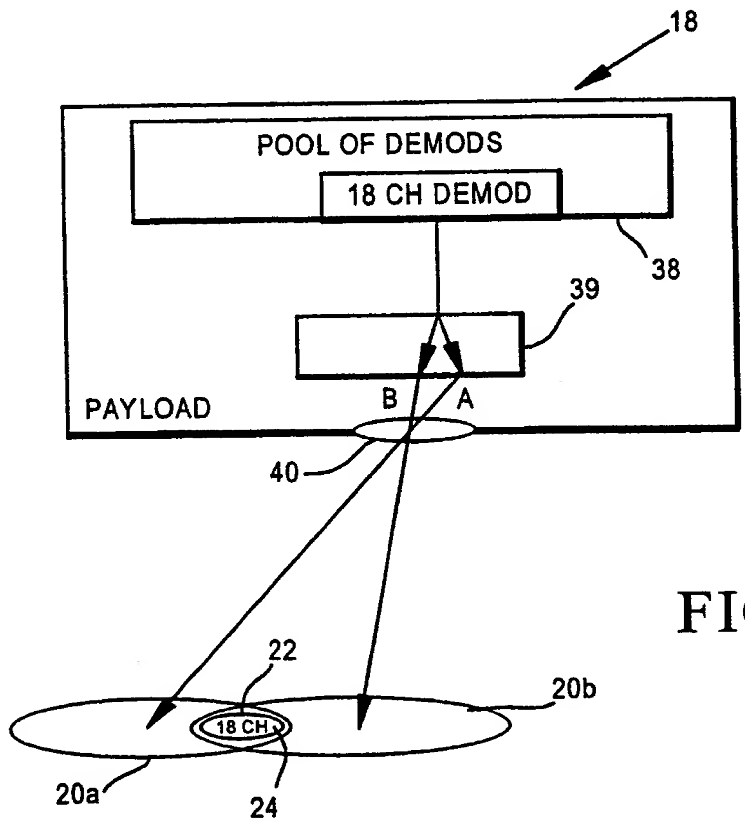
18
POOL OF DEMODS
18 CH DEMOD
38
39
B
A
PAYLOAD
40
22
20b
18 CH
20a
24

FIG.5

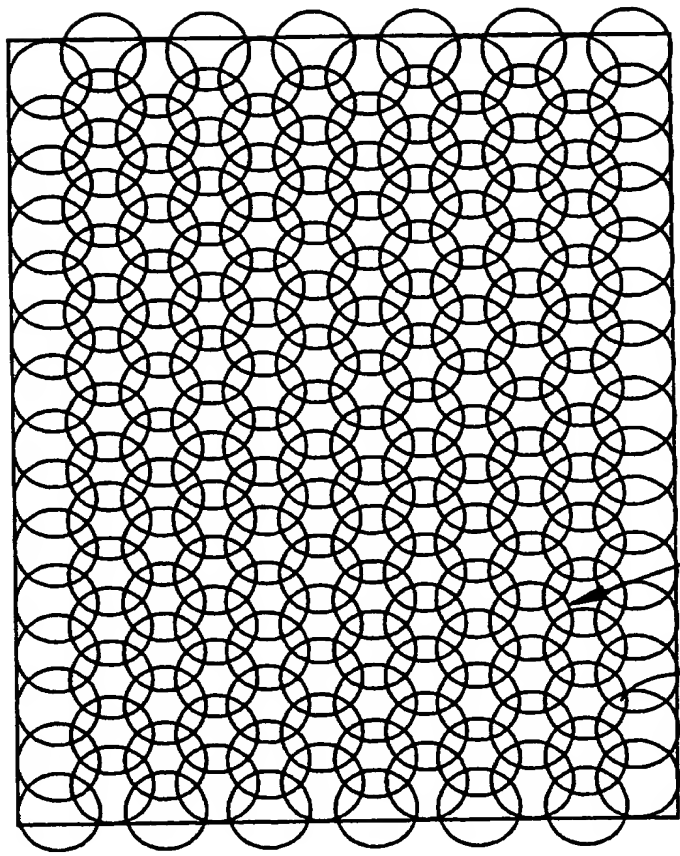

FIG.6

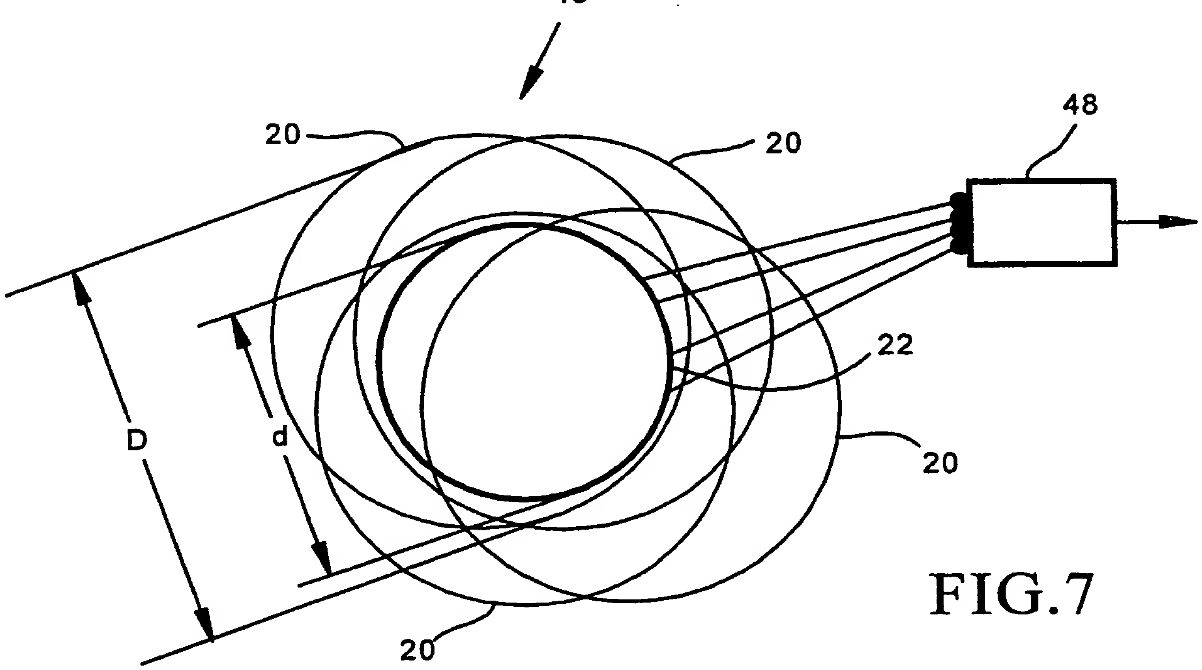

FIG.7

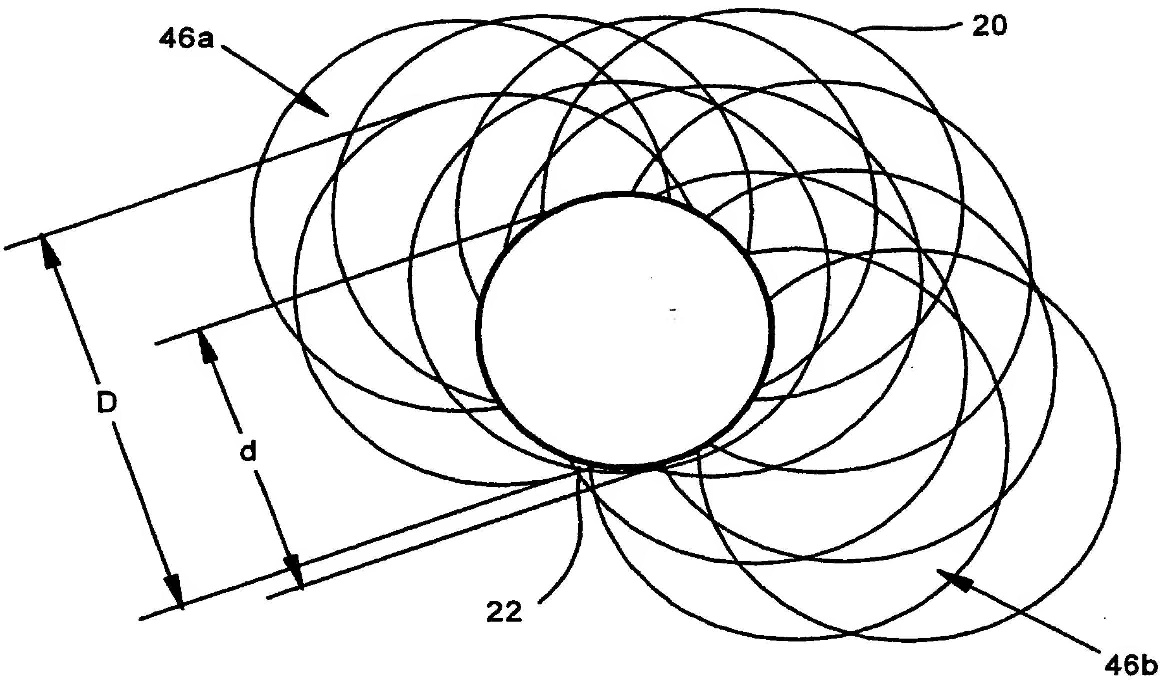

FIG.8

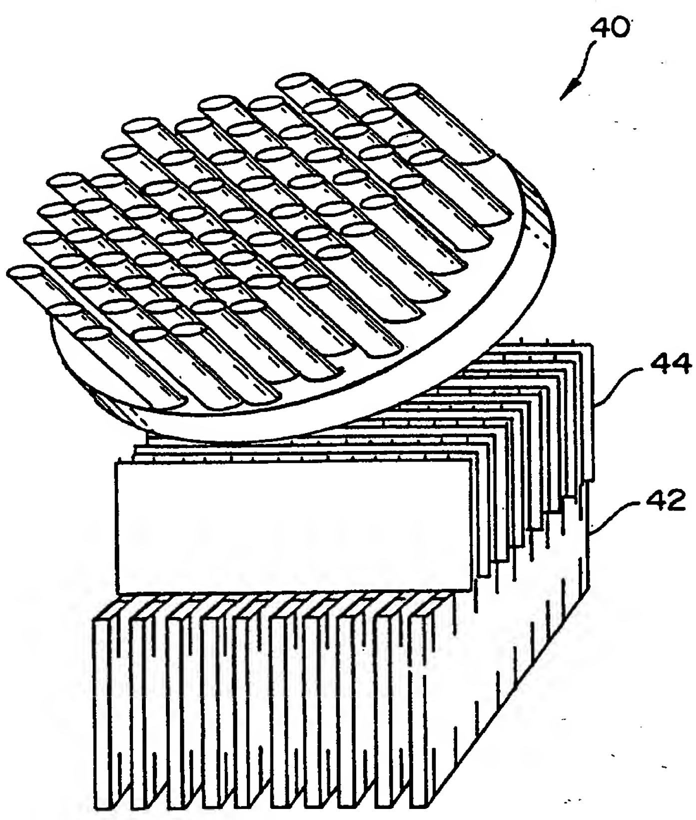

FIG.9

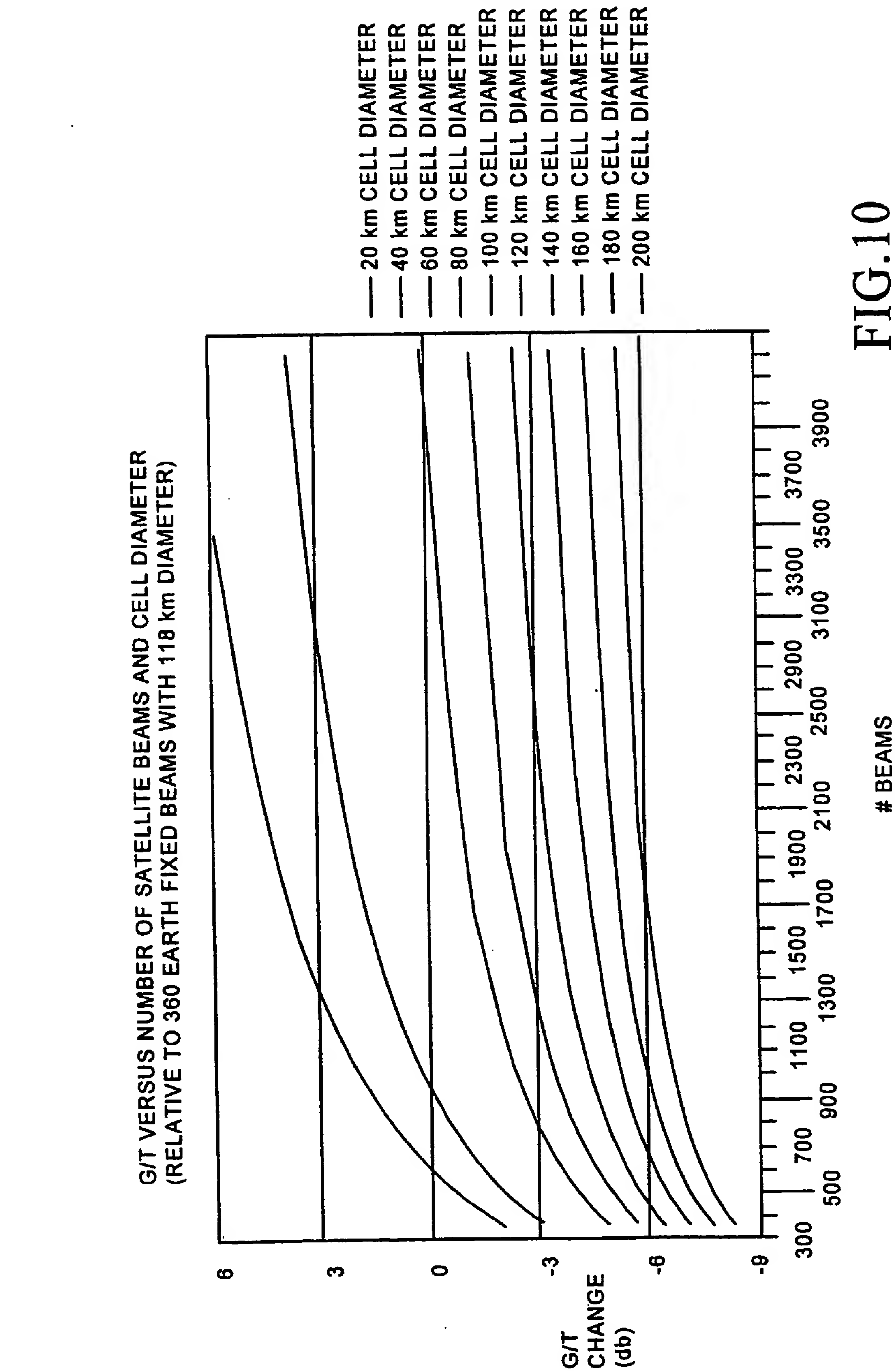
G/T VERSUS NUMBER OF SATELLITE BEAMS AND CELL DIAMETER
(RELATIVE TO 360 EARTH FIXED BEAMS WITH 118 km DIAMETER)
G/T
CHANGE
(db)
6
3
0
-3
-6
-9
300
500
700
900
1100
1300
1500
1700
1900
2100
2300
2500
2900
3100
3300
3500
3700
3900
BEAMS
20 km CELL DIAMETER
40 km CELL DIAMETER
60 km CELL DIAMETER
80 km CELL DIAMETER
100 km CELL DIAMETER
120 km CELL DIAMETER
140 km CELL DIAMETER
160 km CELL DIAMETER
180 km CELL DIAMETER
200 km CELL DIAMETER

FIG.10

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(75) Inventors/Applicants *(for US only)*: DELACHAPELLE, Michael [US/US]; 242 W. Lake Sammamish Parkway S.E., Bellevue, WA 98008 (US). MORSE, David, C. [US/US]; 15835 SE 50th Street, Bellevue, WA 98006 (US). QUADRACCI, Leonard, Jon [US/US]; 4947 SW Forney Street, Seattle, WA 98116 (US).

(74) Agent: NELSON, Lawrence, W.; The Boeing Company, P.O. Box 3707, M/S 13-08, Seattle, WA 98124-2207 (US).

(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

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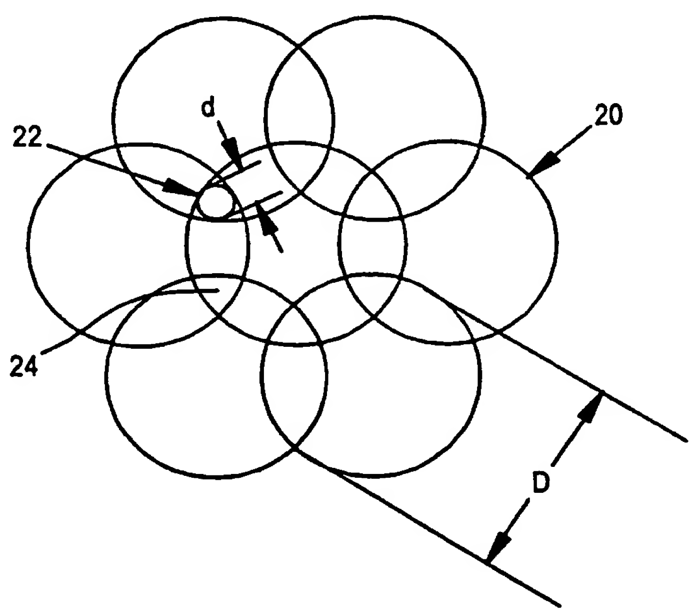
(54) Title: BEAM OVERLOADING SOLUTION FOR OVERLAPPED FIXED BEAMS



(57) Abstract

The present invention relates to a method for allocating beams transmitted from, and received at, positions in Earth orbit for communicating with portable, mobile and fixed terminals and gateways by forming footprints using fixed beam antennas on board satellites flying in orbits below geosynchronous altitude. The footprints illuminate an Earth-fixed grid, including Earth-fixed cells. The spacing of the beams is reduced to create a cluster of beams which operates as a single entity wherein a ratio of beams is an integer multiple n of an amount of down-converters. Responsibility for communication with the target Earth-fixed cell is switched from a first of the cluster of beams to a second of the cluster of beams when the target Earth-fixed cell is within an overlap region shared by the first and the second of the cluster of beams.

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INTERNATIONAL SEARCH REPORT

Inte   nal Application No
PCT/US 99/18285

A. CLASSIFICATION OF SUBJECT MATTER
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According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
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Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 736 959 A (PATTERSON DAVID PALMER ET AL) 7 April 1998 (1998-04-07) abstract column 6, line 9 -column 10, line 18 column 32, line 40-54 column 34, line 51 -column 35, line 26 figures	1,2
A	EP 0 805 567 A (TRW INC) 5 November 1997 (1997-11-05) abstract column 2, line 3-33 column 3, line 4-33 column 3, line 56 -column 4, line 13 figure 1 claims 1,4	1,2

[ ] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
29 March 2000	05/04/2000

Name and mailing address of the ISA	Authorized officer
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1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/US 99/18285

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5736959 A	07-04-1998	US 5408237 A	18-04-1995
		US 5548294 A	20-08-1996
		US 5740164 A	14-04-1998
		AT 146637 T	15-01-1997
		AU 3176893 A	07-06-1993
		CA 2121349 A	13-05-1993
		DE 69216112 D	30-01-1997
		DE 69216112 T	12-06-1997
		EP 0611501 A	24-08-1994
		JP 8500216 T	09-01-1995
		WO 9309614 A	13-05-1993
		AT 182729 T	15-08-1999
		AU 3054992 A	07-06-1993
		CA 2121587 A	13-05-1993
		DE 69229678 D	02-09-1999
		EP 0611500 A	24-08-1994
		EP 0935349 A	11-08-1999
		WO 9309613 A	13-05-1993
EP 0805567 A	05-11-1997	US 5708965 A	13-01-1998
		JP 2971414 B	08-11-1999
		JP 10041870 A	13-02-1998
		NO 971968 A	31-10-1997